

A RAMAN SPECTROSCOPIC SENSOR FOR ON-SURFACE PLANETARY REMOTE SENSING. ALIAN WANG¹, ENRIQUETA CORTEZ², AND LARRY A. HASKIN¹. ¹Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, One Brookings Drive, St. Louis, MO (alianw@levee.wustl.edu). ²Monsanto Company, 800 North Lindbergh Boulevard, St. Louis, MO 63167

Laser Raman spectroscopy holds great promise for on-surface planetary mineral determination [1-5]. It is especially useful for oxy-anionic minerals such as silicates, carbonates, sulfates, and phosphates even in trace amounts. It can identify some oxide and sulfide minerals, and is sensitive to water, OH⁻, and organic carbon. It can thus characterize igneous and sedimentary rocks and products of their weathering, alteration, and metamorphism. Recent developments in instrumentation make it feasible to build a small, robust Raman spectrometer for use on a planetary lander or rover. We envision the spectrometer as having two parts: an agile sensor head that can be positioned by a robotic arm, and a spectrograph that resides on the lander or rover and is connected to the sensor head through electrical and fiber optical cables.

This work describes results obtained with a sensor head that we have designed for on-surface planetary use and are testing at breadboard level. The functions of the sensor head are to generate the laser exciting line, collimate, filter, and focus it on the sample, collect the Raman-backscattered radiation, filter out the intense, Rayleigh-backscattered and reflected exciting line, and direct the Raman signal into the fiber-optic cable that leads to the spectrograph.

Fig. 1 is a schematic diagram of the sensor head. The laser is a small, low-power (<30 mW output), high conversion efficiency, distributed-feedback (DFB) or distributed-Bragg-reflector (DRB) diode. It operates at a wavelength of ~685 nm, which provides high Raman scattering efficiency, excites relatively little fluorescence, and allows high CCD detection efficiency. Placing the laser inside of the sensor head reduces power loss from fiber coupling and maintains a linear polarization of the beam on the sample. A dielectric bandpass filter removes spontaneous emissions from the laser. A mirror and a Super-Notch-Plus filter directs the exciting beam to a microscope objective, which focuses the beam onto the sample. The objective also collects light scattered back from the sample and directs it through two Super-Notch-Plus filters that reduce the Rayleigh-backscattered radiation by a factor of 10^{-8} while passing the Raman-backscattered radiation with high efficiency. The purified Raman signal then passes through a condensing objective and into the fiber optic cable.

The work described here addresses two aspects of the sensor head design: (1) A general demonstration of the operation and efficiency of the system, and (2) the trade-off between the power density of the laser beam on the sample and the depth of the sampling field in a simple field instrument without precision focusing capability.

For the general demonstration, the sensor head was coupled through its fiber-optic cable via a 1" dia., 1" focal length bi-convex lens into the entrance slit (300 μ m) of a laboratory spectrograph (the third stage of a SPEX 1877 TRIPLEMATETM, asymmetric Czerny-Turner configuration, 0.6 m focal length, f/6.3 aperture, 870 cm^{-1} spectral coverage with a 1,800 lines/mm grating, backthinned CCD detector.) Typical integration times for mineral and rock tests were 1–10 minutes using an 8 \times Nachet objective (N.A. = 0.25). Ten minute integration time is considerably longer than anticipated for a spectrometer designed for analysis on a planetary surface (~2 minutes per spectrum) because the laboratory spectrograph was inefficiently coupled to the sensor head. Fig. 2 shows spectra for five mineral specimens. The signal-to-noise ratio is high, so mineral identification is straightforward.

Fig. 3 shows spectra from two rock chips, an impactite from the Manson impact structure and an altered amygdular basalt. In the first, the principle minerals, quartz and K-feldspar are readily seen. So is calcite found in a vein that crosses the specimen. The second, an altered basalt with amygdular fill, shows an identifiable spectrum for partially altered pyroxene, a phyllosilicate alteration product, and zeolite (thomsonite) and calcite in amygdules. Complications such as surface roughness, grain-size effects, multigrain-scattering, and mineral absorptivity [2] reduce peak intensities for the rock chips below those observed for the mineral specimens. For this reason, the rock spectra contain lines arising from laser side-mode emissions that were not adequately filtered out in these experiments. (These side-mode lines, connected by the vertical dashed lines in Fig. 3, arise because an ordinary diode laser rather than a DFB or DBR laser was used for these experiments.)

We determined the effective depths of the sampling field for this sensor head using several microscope objectives (8 \times Nachet 0.25 NA, 10 \times Olympus 0.3 NA, 20 \times Olympus 0.3 NA, 20 \times Leitz 0.46 NA, and 50 \times Olympus 0.55 NA), as follows. The beam was focused on a single grain of quartz or olivine, and a spectrum was taken. The sample was then moved in increments away from the point of focus, and a spectrum was taken at each new distance. Fig. 4 shows the results of these tests for the 465 cm^{-1} peak of quartz. The signal-to-noise ratio decreases as a function of the de-focusing distance. As seen in Fig. 4, objectives in the range of 8 \times to 20 \times and NA of 0.25 to 0.3 provide good enough signal-to-noise at focus and distinguishable peaks at distances as great as ± 7 mm from the focus position. A spectrum of quartz taken at a distance of 6.8 mm from the focus position is shown in upper Fig. 4.

This latitude in effective depth of the sampling field enables the use of Raman spectrometers without precise focusing capability. The sensor head with a simple stop can be placed against a rock or soil surface (Fig. 1) by a lander or rover arm, and roughness of the sample surface will not be a barrier to obtaining informative spectra. The uncertainty in actual distance between the sample and the objective will not interfere with quantitative mineral mo-

dal analysis if the point-counting method is used [2].

References: [1] Wang *et al.*, *J. Geophys. Res.* **100**, 21,189 - 21,199, 1995; [2] Haskin *et al.*, this volume; [3] Jolliff *et al.*, this volume; [4] Wang *et al.*, this volume; [5] Israel *et al.*, *PLPSC27*, 583-584 and this volume.

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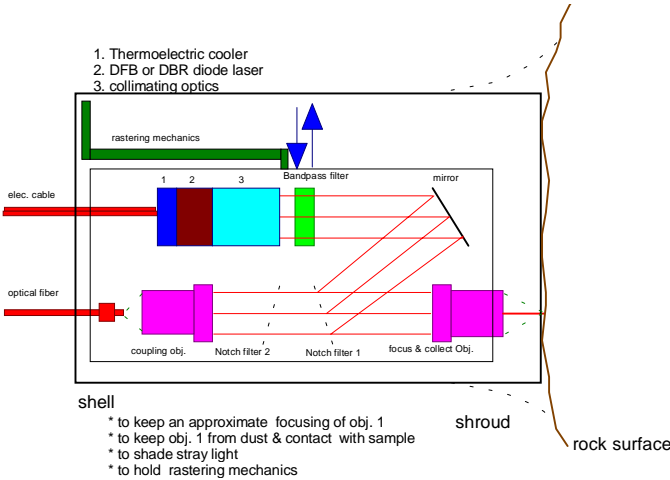


Fig. 1. Schematic diagram of sensor head of Raman system for on-surface planetary remote sensing.

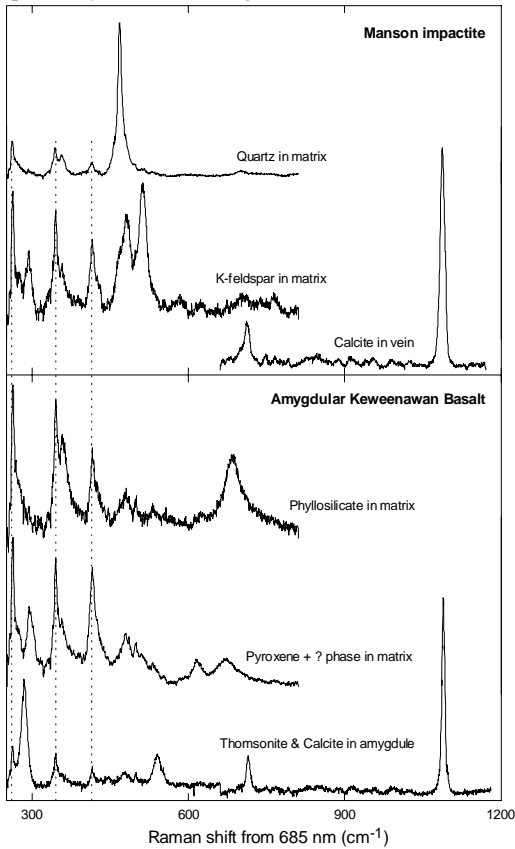


Fig. 3. Mineral spectra from altered terrestrial rocks.

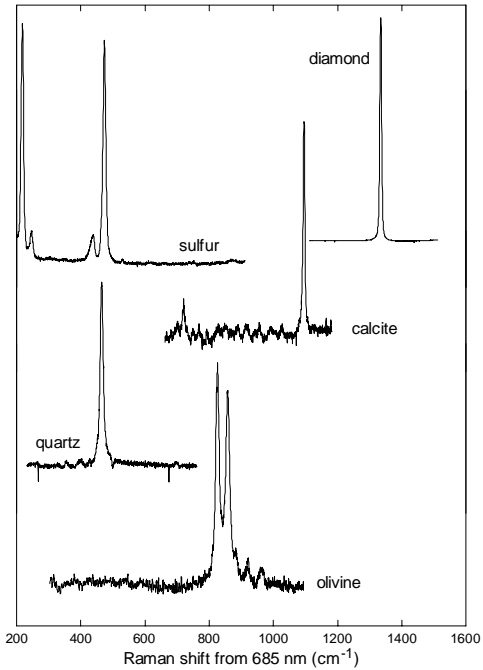


Fig. 2. Sensor head demonstration of mineral spectra

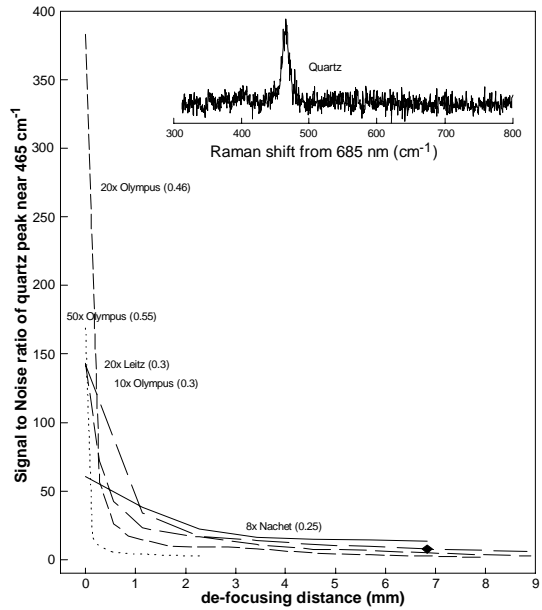


Fig. 4. Effect on signal-to-noise ratio of defocusing for several microscope objectives; quartz spectrum is for the 10x Olympus objective at 6.8 mm – see diamond point.